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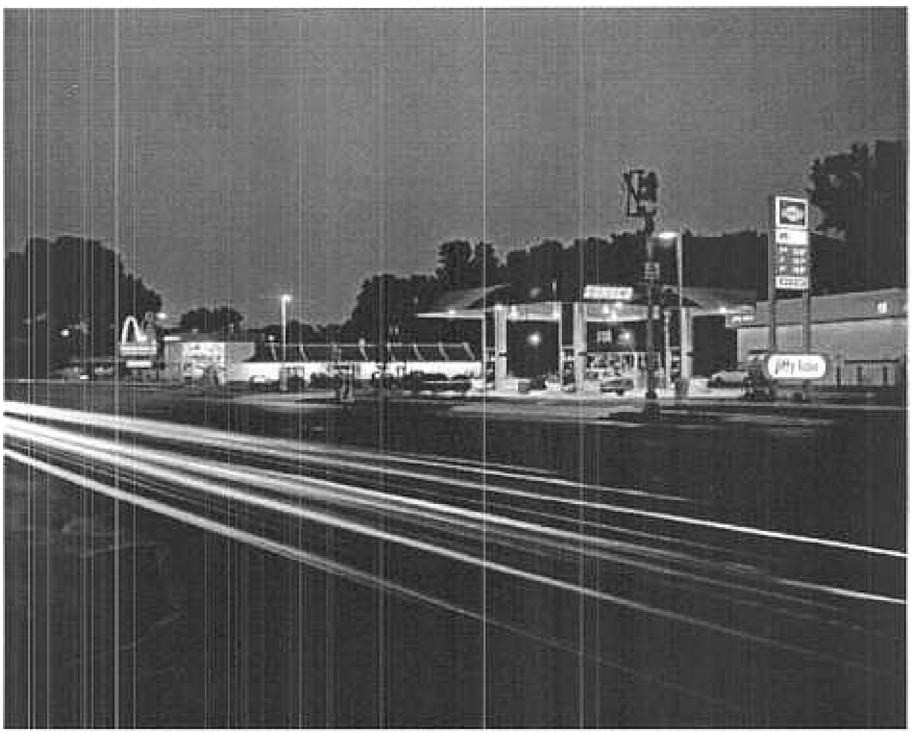

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Summary

This report describes an evaluation of gas station canopy lighting using 3 types of luminaires: drop-lens, non-cutoff luminaires, in which the lamp is visible from far away; flat-lens, full-cutoff luminaires; and drop-lens, cutoff luminaires, in which the lamp is not visible from far away. The evaluations considered photometric conditions, energy efficiency, the tendency of drivers to turn into the station, patron opinions, the opinions of a panel of community leaders, and gasoline sales. The evaluation was carried out between April 12 and May 11, 2001.

All three installations had the same power density and, thus, energy consumption. The installation using the drop-lens, non-cutoff luminaires produced lower illuminances under the canopy but greater glare and more light trespass than the full-cutoff and cutoff luminaires. These findings were predictable from the luminous intensity distributions of the luminaires. The percentage of drivers turning in to the station and the mean number of gallons of gasoline sold daily increased immediately following the change of lighting from the drop-lens, non-cutoff luminaires to the flat-lens, full-cutoff luminaires, and again when the latter were changed to the drop-lens, cutoff luminaires. These changes in drivers' behavior suggest that better lighting encourages drivers to use a gas station, but a more comprehensive study should be conducted to validate these findings. As for opinions, the patrons saw little difference between the three lighting installations. However, the panel, which compared several gas stations, gave the highest level of acceptance for the drop-lens, cutoff lighting and the lowest (at a different gas station) for the drop-lens. non-cutoff luminaire.

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1. Introduction

A brightness war has broken out between gas stations throughout America. The goal is to have the brightest under-canopy lighting in the local market. If one gas station in an area installs lighting with greater brightness, competing stations feel obliged to be brighter still. The result of this escalating process has been a steady increase in the illuminances produced by under-canopy lighting with the result that, today, illuminances on the apron under the canopy commonly exceed 1000 lx (100 fc), more than double the illuminance used in many offices. Further, the luminaires commonly used to produce such illuminances are designed with a drop lens where the lamp extends into the lens, which makes it visible from far away. Consequently there has been an increased level of complaints from nearby residents and drivers about glare and light trespass. These complaints have increased pressure on local officials to correct the situation.

Ruud Lighting has designed a new series of under-canopy luminaires that hide the light source at the angles from which under-canopy luminaires are commonly viewed, thus reducing light trespass and glare. These luminaires can be fully recessed or fitted with a drop lens that prevents viewing the light source from far away. It is claimed that these luminaires can be used to produce the same illuminance on the pump area as luminaires that do have a view of the light source from far away and that the drop-lens luminaire will produce an impression of sparkle rather than glare.

2. Objectives

The objective of this evaluation was to quantify the effects of the three types of canopy lighting luminaires in terms of

Photometric conditions related to visibility at the pumps, visual discomfort, and light trespass

Energy efficiency of the installation

Tendency of drivers approaching the gas station to turn in to it

Patrons' opinions regarding task visibility for filling the vehicle with gas, plus an overall impression of visual comfort

Opinions of a panel of community leaders regarding visual amenity

Gasoline sales

3. Method

3.1 Evaluation site

The evaluation was conducted at a Sunoco gas station at 1390 Allen Street, Springfield, MA, owned by F. L. Roberts and Company, Inc. The cover of this report shows a photograph of the gas station. Figure 1 shows a plan of the gas station, which is located between a restaurant and a fast food facility along a divided highway on the edge of Springfield. There is a set of traffic signals immediately before the gas station to allow traffic from a side road adjacent to the gas station to access the divided highway. The gas station has three pumping positions and a small kiosk, all under a 16-ft-high, rectangular canopy (see Figures 2, 3, and 4). The gas station attendant is located in the kiosk and, in addition to supervising the sale of fuel, sells cigarettes, lottery tickets, confectionery, and other minor items. There is no convenience store on the site, the rest of the site being occupied by a fast oil-change facility.

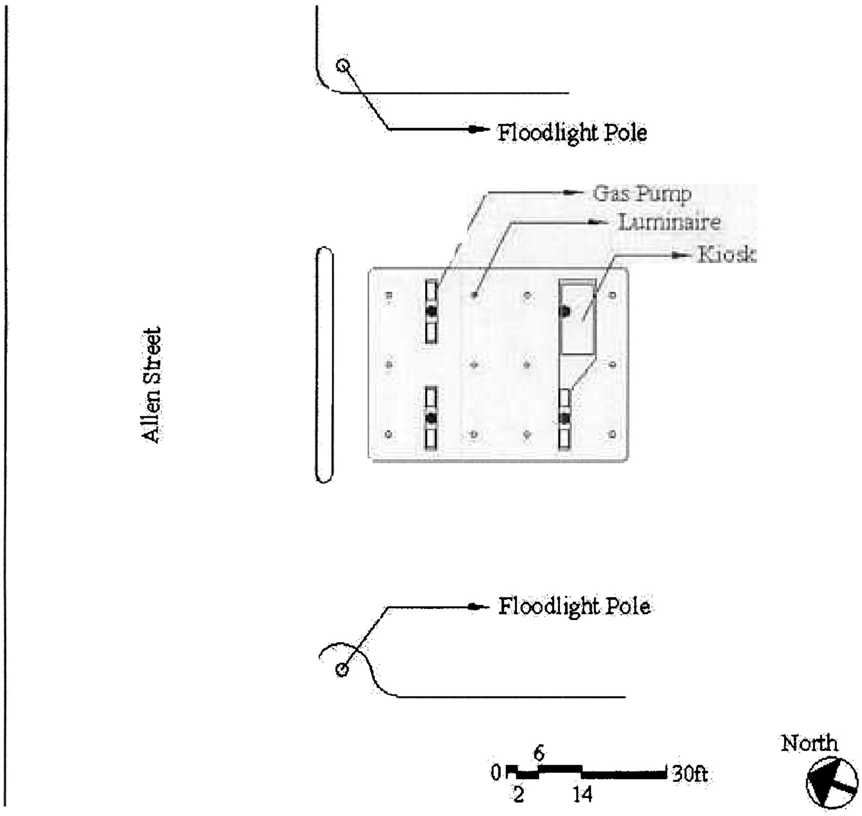

Figure 1. Plan of the evaluation site

The pumps at the site are relatively new and finished in the Sunoco corporate colors. The canopy has painted colored sides; the underside seen by people in the gas station is brushed aluminum. The driving surface under the canopy is concrete with a reflectance of 0.24, while that of the rest of the site is asphalt.

Figure 2. Photograph of the original lighting

Figure 3. Photograph of the new flat-lens lighting

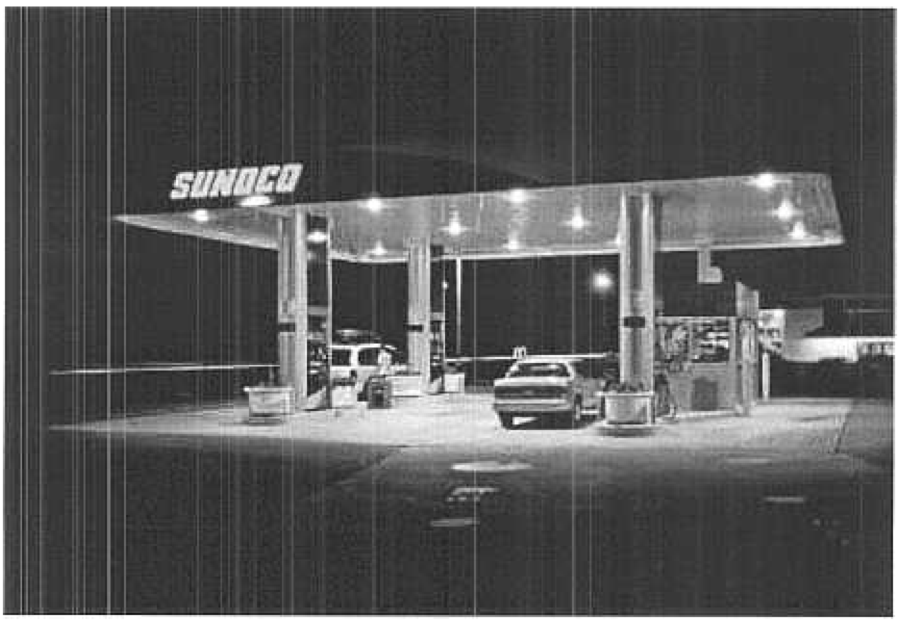

Figure 4. Photograph of the new drop-lens lighting

3.2 Lighting

Three different canopy lighting installations were evaluated. The original lighting installation at the site consisted of twelve LSI Petroleum Super Scottsdale recessed luminaires, arranged in a 4 x 3 regular array (see Figure 2). Each luminaire contained one 320-W vertically burning, pulse-start metal halide lamp. The lamp projects down into the glass refractor of a non-cutoff luminaire, according to the classification of the Illuminating Engineering Society of North America (IESNA) (Rea, 2000). The brightness of the luminaire is very high at many angles because the lamp is visible through the refractor. This luminaire is widely used by gas stations and is advertised as extending the light beyond the canopy and providing better long-range visibility.

For the second lighting installation, twelve Ruud Lighting Constellation luminaires with a flat, clear-glass lens replaced the existing luminaires. Each luminaire contained one 320-W vertically burning, pulse-start metal halide lamp (see Figure 3). Neither the lamp nor the luminaire projects below the plane of the canopy. The luminous intensity distribution of the luminaire conforms to the IESNA full-cutoff classification, whereby most of the light is directed downward, under the canopy.

The third installation used the same equipment as the second, except that the flat lens was replaced by a prismatic glass, drop-lens option (see Figure 4). The drop lens extends 2.5 in. below the canopy. This drop lens modifies the luminous intensity distribution of the luminaire slightly, so this luminaire still conforms to the IESNA cutoff classification. Certainly, the drop lens does change the appearance of the luminaire as seen from a distance because the prismatic element provides some small areas of high brightness.

For all three installations, the entrance to and exit from the gas station were each illuminated by a single floodlight containing a single 1000-W metal halide lamp mounted on a 20-ft pole (see Figure 1).

3.3 Procedures

An evaluation team visited the gas station twice for each lighting installation to record photometric measurements, the frequency of drivers turning in, and patron opinions. For the existing installation, the visits were made on the evenings of Thursday and Friday, April 12 and 13. For the new flat-lens installation, the visits were made on the evenings of Thursday and Friday, April 26 and 27. For the new drop-lens installation, the visits were made on Thursday and Friday, May 10 and 11. On each evening, the team arrived at the station about 8:00 p.m., about dusk, with the canopy lighting already on. A variety of photometric measures were taken after 9:00 p.m. (well after sunset). To measure the frequency of turning in, the number of vehicles passing the front of the station was recorded on a hand-held counter in ten-minute intervals, as was the number of vehicles that turned into the station. Accurate counting was easy to obtain because the station was on one side of a divided highway and drivers could only enter the station from one direction. Patrons fueling their vehicles were approached and asked to complete a short questionnaire about the lighting of the gas station (see Appendix A). Those completing the questionnaire were given a $1 Massachusetts State lottery ticket. These activities continued until about 10:00 to 10:30 p.m., depending on the number of drivers entering the station.

A panel of six community leaders was formed, including one city planner, one lighting expert, two utility representatives, one senior manager from a major corporation, and one employee of a small business. The panel was divided into two groups, which looked at the same six gas stations, including the site evaluated. At each site, their vehicle was first parked on a property adjacent to the gas station so the panel could answer a short questionnaire about the appearance of the gas station (see Appendix B) from a distance. The vehicle was then moved into the gas station so the panel could assess the lighting. This procedure was conducted on May 8, when the evaluation site was lighted by the new drop-lens installation. The other gas stations visited were illuminated by a range of lighting types (see Appendix C).

The daily gasoline sales data from May 1, 2000, to May 31, 2001, were supplied by F. L. Roberts and Company, Inc. The lighting power density of the three lighting installations was calculated from the power demand of the luminaires and the area of the gas station.

4. Results

4.1 Photometry

4.1.1 Illuminance under the canopy

The illuminances produced by the three lighting installations on the concrete pavement under the canopy were measured along three axes, identified as A, B, and C on Figure 5 (see page 8). The measurement points were separated by 2-ft intervals. The mean illuminances, and the associated standard deviations for each axis, are given in Table 1. Table 1 shows that the mean illuminance on all three axes is lower and the standard deviation is smaller under the original lighting than under either of the new lighting installations. The decline in light output from the 32-W pulse-start metal halide lamps of the original lighting can be estimated from the manufacturer's data and the estimated hours of use. The attendant manually controls the lighting at the gas station, which opens at 5:45 a.m. The attendant turns on the lighting at opening and keeps it on until about one hour after sunrise. The lighting is turned off during the daytime. The lighting is turned on again about one hour before sunset and is kept operating until 11:00 p.m. when the gas station closes. The original lighting was installed in April 1999. The hours of use of the lamps from April 1999 to April 2001, when the evaluation was made, are calculated as 6538 hours. These calculations are based on the hours of sunrise and sunset in the middle of each month and the hours at which the station opens and closes. From the manufacturer's data, for base-up operation, the light output of the 320-W pulse-start metal halide lamps will have decreased to 77% of initial light output. The other element involved in the decline in light output over time, dirt depreciation, can be quantified by taking the standard values for the luminaire dirt depreciation factor for outdoor lighting. The IESNA gives values of luminaire dirt depreciation for road lighting (IESNA, 1993). For moderately clean conditions, after two years, the luminaire dirt depreciation factor is 0.88. The combined effect of decline in light output and dirt depreciation on light output from the luminaire can be estimated by multiplying these two factors together, that is, 0.77 x 0.88 = 0.68. Then by dividing the mean illuminances measured for the original lighting by this combined factor, the mean illuminances that would have occurred when the original lighting was new can be estimated. These mean illuminances are given in Table 1 in italics. Correcting for the decline in light output and dirt depreciation over time increases the mean illuminances for the original lighting, but not enough to eliminate the difference between the original lighting and the new lighting installations. These residual differences in mean illuminance are caused by the different luminous intensity distributions of the three luminaire types used because the same lamp type and same operating conditions are used in all three luminaires.

Table 1. Mean illuminance (and the associated standard deviation) measured along each axis under the three lighting installations (lx). Also shown, in italics, are the mean illuminances estimated for the original lighting when new.

Lighting installation	Axis A	Axis B	Axis C
Original lighting (measured)	299 (76)	378 (98)	265 (67)
Original lighting (estimated as new)	*440*	*559*	*390*
New flat-lens lighting	642 (191)	1055 (201)	698 (152)
New drop-lens lighting	643 (166)	906 (190)	664 (158)

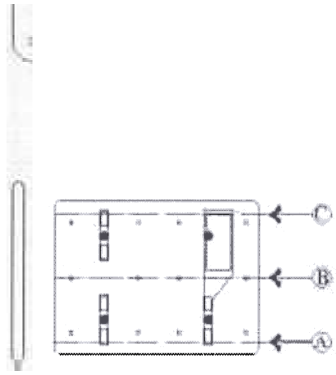

Figure 5. Evaluation site plan indicating the locations from where illuminance measurements were taken

4.1.2 Glare

Given the different luminous intensity distributions of the luminaires used in the three lighting installations, they are expected to produce different levels of glare. The metric of glare used is the glare ratio, developed by the Lighting Research Center for the Exterior Lighting Evaluation Toolkit (Boyce and Eklund, 1998). The glare ratio is the ratio of the illuminance reaching the eye of an observer from above and below a horizontal plane containing the direction of view. The criterion level for the glare ratio is 4.0. Glare ratios above 4.0 are considered to be glaring while those below 4.0 are considered to be free from glare. The glare ratio was measured from three positions on the borders of the site, as shown in Figure 6 (see page 9). Table 2 gives the measured glare ratios for the three lighting installations and shows that the original lighting is much more glaring than either of the new lighting installations. The least glare is seen in the new flat-lens installation. The glare ratios for the original lighting were more than 4.0 at all three positions, while the glare ratios for the two new lighting installations were less than 4.0 at all three positions. The higher light output of the original lighting when new would have little effect on these glare measurements because the glare ratio is based on light distribution, and the light output of the luminaires is unchanged by the decline in light output over time.

Table 2. Glare ratio from three positions for each lighting installation

Lighting installation	Position A	Position B	Position C
Original lighting	9.8	7.2	6.2
New flat-lens lighting	1.5	0.8	1.3
New drop-lens lighting	2.6	3.0	2.3

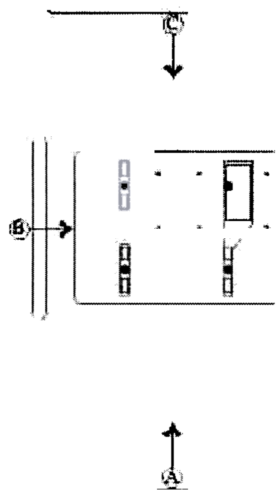

Figure 6. Evaluation site plan indicating the locations from where illuminance measurements were taken

4.1.3 Light trespass

The amount of light trespass perceived to be caused by a lighting installation depends on the amount of light present in the surroundings. There are two ways to quantify light trespass. The first is to measure the illuminance at the boundary of the site on a vertical plane facing towards the site (IESNA, 1999). Table 3 shows illuminances obtained at five different positions around the site, as shown in Figure 7 (see page 10). Table 3 shows that the original lighting always produces greater light trespass than either of the new lighting installations. These measurements were taken with the reduced light output of the light sources as found. If the light sources in the original lighting had been new, the illuminances would have been increased by 47% (the reciprocal of 0.68; see Section 4.1.1), making the light trespass even worse.

Table 3. Light trespass illuminances for five positions for the three lighting installations (lx).

Lighting installation	Position A	Position B	Position C	Position D	Position E
Original lighting	95	115	239	108	98
New flat-lens lighting	30	61	89	42	30
New drop-lens lighting	43	74	108	58	47

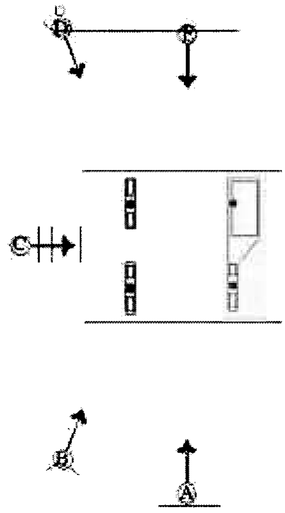

Figure 7. Evaluation site plan indicating the locations from where illuminance measurements were taken

One limitation of simple measurements of illuminance at a boundary is that they ignore the amount of light outside the boundary from other sources, and hence ignore the impact of the light trespass. The second way of assessing light trespass overcomes this problem. It is to measure vertical illuminances at eye level at the boundary of the site with the normal to the plane of measurement directed towards the installation, and then 180° away from the site. A ratio of the measured illuminances less than unity implies that the site receives more light from the surroundings than the site delivers to the surroundings. If the ratio is greater than unity, then the site delivers more light to the surroundings than the surroundings deliver to the site. The larger the ratio, the more likely complaints about light trespass are to occur.

Measurements were made at five positions on the border of the site, as shown in Figure 7. Table 4 gives the measured ratios of vertical illuminances. Examination of Table 4 shows that the light trespass is always greater with the original lighting installation than with either of the new lighting installations, and particularly so for the new flat-lens installation. It is also worth noting that the light trespass illuminance ratio varies greatly with measurement position. The light trespass illuminance ratios are high for positions A and C, where the surroundings are dark, and low for positions B, D, and E, where the surroundings are bright. This difference is either because the area floodlights and the illuminated sign illuminate the entrance and exit from the site (positions B and D), or because of the parking lot lighting of the adjacent fast food facility (position E). Despite this variability, it is clear that the original lighting installation is more likely to generate complaints of light trespass than either of the new lighting installations.

Table 4. Light trespass illuminance ratios for five positions for the three lighting installations.

Lighting installation	Position A	Position B	Position C	Position D	Position E
Original lighting	9.7	1.3	18.1	2.1	4.1
New flat-lens lighting	4.3	0.5	9.8	0.8	1.4
New drop-lens lighting	4.8	0.6	15.0	1.2	2.5

4.2 Energy efficiency

The same 320-W pulse-start metal halide lamp was used in the same number of luminaires (12) for the canopy lighting in all three lighting installations. Therefore, the power demand for the three lighting installations is the same (4.38 kW) as is the lighting power density 2.55 W/ft^2 (27.4 W/m^2). This value is based on the area of the site under the canopy. Given that the lighting is turned on and off by the attendant when the station opens and closes, the hours of use for the three lighting installations should be the same, so the actual energy consumption should also be the same. Where the three lighting installations differ is in the efficiency with which they deliver a fixed illuminance to a defined area (Rea and Bullough, 2001). This efficiency can be quantified by calculating the wattage required to deliver a mean 100 lx to the concrete pavement under the canopy. For this metric, the original lighting, as found, has an efficiency of 1394 W/100 lx, while the new flat lens installation has an efficiency of 549 W/100 lx and the new drop-lens installation has an efficiency of 593 W/100 lx. Even when corrected for the decline in light output from new, as described in Section 4.1.1, the original lighting has an efficiency of only 948 W/100 lx. Clearly, the new lighting installations are more efficient at delivering light to the area under the canopy than the original lighting installation.

4.3 Tendency of drivers to turn in

The tendency of drivers to turn in to the gas station was defined as the percentage of vehicles that turned in to the gas station. Table 5 shows the percentage of vehicles turning in for the three lighting installations. Examination of Table 5 shows an increase in the percentage of vehicles turning in for the new flat-lens and drop-lens lighting over the original lighting.

Table 5. Time duration over which traffic flows were recorded, number of vehicles passing during that time, number of vehicles turning into the gas station during that time, and number of vehicles turning in as a percentage of the total number passing and turning in.

Lighting installation	Time duration for which traffic flow was recorded (mins)	Number of vehicles passing	Number of vehicles turning in	% turning in
Original lighting	210	2150	41	1.87
New flat-lens lighting	210	1991	49	2.40
New drop-lens lighting	200	2015	59	2.84

4.4 Patron opinions

The percentage of patrons agreeing with each of the statements in the questionnaire in Appendix A under the three different lighting installations are given in Table 6. The differences between the level of agreement for each statement under the three lighting installations were tested for statistical significance using the *k*-sample chi-square test. Only the response to the statement "The amount of light in different areas of this gas station varies a lot" shows a statistically significant difference. Significantly fewer drivers agree with this statement for the original lighting than for the new flat-lens and drop-lens lighting. Again, this is probably caused by the different luminous intensity distributions of the luminaires used. The luminous intensity distribution of the luminaire used for the original lighting is much wider than for the flat-lens and drop-lens lighting. This wider luminous intensity distribution spreads light more uniformly over the site relative to the other luminaires, which concentrate the light under the canopy. As for the other statements, the lack of statistical significance between the three lighting installations implies that all are considered comfortable, and that for all three, the lighting is neither too bright nor too dim, there is plenty of light to see under the hood, there are few reflections that cause difficulty, and the light fixtures are not considered too bright when seen from the street. Further, all three lighting installations were equally effective in attracting people to pull in, making them feel safe, and in being attractive overall. As for the comparisons with other gas stations, all three lighting installations were considered predominantly better than those at the other stations.

Table 6. Percentage of drivers in the gas station agreeing with each statement in the questionnaire

Statement	Original lighting (n = 26)	New flat-lens lighting (n = 30)	New drop-lens lighting (n = 53)
Overall, the lighting in this gas station is comfortable (n.s.*)	96%	100%	94%
The lighting is too bright for pumping gas and checking my car (n.s.)	15%	10%	13%
The lighting is too dim for pumping gas and checking my car (n.s.)	12%	10%	2%
There is enough light to see under the hood of my car if I need to (n.s.)	92%	93%	94%
The lighting causes reflections that keep me from seeing well (n.s.)	8%	13%	8%
The amount of light in different areas of this gas station varies a lot ($p<0.05$)	15%	50%	32%
The light fixtures are too bright when seen from the street (n.s.)	8%	7%	8%
The lighting at this gas station attracted me to pull in (n.s.)	62%	37%	57%
The lighting at the gas station makes me feel safe (n.s.)	88%	93%	96%
Overall, the lighting in this gas station is attractive (n.s.)	85%	87%	92%
How does the lighting in this gas station compare to that of other gas stations you use? (n.s.)	Worse 4% Same 15% Better 81%	Worse 0% Same 40% Better 60%	Worse 0% Same 30% Better 70%

*** n.s. = no statistically significant difference between the three lighting installations***

The other part of the questionnaire given to drivers in the gas station asked them to identify, from a list of descriptive words, their impression of the lighting of the gas station. Table 7 lists the percentage of drivers who marked each word as applicable. The words are arranged as opposing pairs. No statistical tests were performed on the data summarized in Table 7. However, an examination of Table 7 for differences between the lighting installations reveals that fewer people consider the flat-lens lighting sparkling and colorful, opinions that probably have something to do with the brightness of the luminaires used in the other lighting installations. However, the flat-lens lighting is more frequently considered well maintained and modern than the other lighting installations. The original lighting is more frequently considered safe as well as glaring relative to the other two lighting installations. Again, these perceptions may have to do with the brightness of the luminaire used in the original lighting. Finally, the new drop-lens lighting is more frequently identified as expensive and comfortable than the other two lighting installations.

Table 7. Percentage of patrons who said each word was applicable.

Word	Original lighting (n = 26)	New flat-lens lighting (n = 30)	New drop-lens lighting (n = 53)
Attractive	50%	50%	55%
Ugly	4%	0%	0%
Well-maintained	62%	73%	59%
Run-down	0%	0%	0%
Clean	69%	67%	55%
Dirty	0%	0%	0%
Bright	77%	77%	74%
Dark	0%	0%	0%
Sparkling	27%	10%	28%
Drab	0%	0%	0%
Colorful	19%	7%	19%
Colorless	0%	0%	4%
Modern	35%	50%	40%
Old-fashioned	0%	0%	0%
Expensive	8%	3%	19%
Cheap	4%	0%	0%
Safe	73%	67%	64%
Dangerous	4%	0%	0%
Comfortable	50%	53%	64%
Glaring	15%	0%	4%

4.5 Panel opinions

The panel of community leaders outlined in Section 3.3 used a 5-point scale to indicate agreement with the statements about the lighting of the gas stations visited: 1 = strongly disagree, 2 = slightly disagree, 3 = neither agree nor disagree, 4 = slightly agree, and 5 = strongly agree (Appendix B). Table 8 gives their mean ratings. Station 2 is the evaluation site. The new drop-lens cutoff lighting was used at the time of the visit by the panel. Station 4 had lighting similar to the original lighting used at the evaluation site. The levels of agreement with statements 1 through 4 were given when viewing the station from a vehicle parked on an adjacent property. The levels of agreement with statements 6 through 8 were given in the gas station.

Examination of Table 8 shows that Stations 2 and 4 produce the extremes of opinion. Station 2 (the evaluation site with the new drop-lens lighting) has the highest level of agreement with the statements "The lighting of this gas station would make me feel safe when using it," "The lighting of this gas station is appropriate for the surroundings," "The lighting of this gas station is comfortable," "There is plenty of light for pumping gas," and most impressively, " I would like to see lighting of this type for all new gas stations." Station 4 (which has the same type of lighting as the original lighting at the evaluation site) shows the highest level of agreement with the statements "The lighting of this gas station attracts attention" and "The light fixtures are too bright when seen from the street" and the lowest level of agreement with the statement "I would like to see lighting of this type for all new gas stations."

Table 8. Mean ratings of agreement given by the panel to each statement about the gas stations visited.

Statement	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
1. The lighting of this gas station attracts attention	3.4	3.9	3.4	4.7	3.0	3.1
2. The lighting of this gas station would make me feel safe when using it	4.0	4.4	3.9	4.3	4.0	4.3
3. The lighting of this gas station is appropriate for the surroundings	3.7	4.3	3.6	2.4	4.1	4.0
4. The light fixtures are too bright when seen from the street	3.0	2.4	2.4	4.4	2.0	2.1
6. The lighting of this gas station is comfortable	3.3	4.0	3.7	3.1	3.4	2.7
7. There is plenty of light for pumping gas	4.1	4.9	4.7	4.6	3.7	4.1
8. I would like to see lighting of this type for all gas stations	2.0	3.9	3.0	1.9	2.7	2.0

The panel was also asked to mark those words from a list that they felt described the lighting of the gas station seen from a vehicle parked in an adjacent property (Question 5). Table 9 shows the number of members of the panel who marked each word for each gas station.

Examination of Table 9 is based on the responses of the majority of the panel, that is, the same word chosen by at least four members of the panel. Using this criterion, all stations visited were described as clean. Apart from the perception of cleanliness, stations 1, 5, and 6 produced no other consistent impression on the panel. Station 2, which is the evaluation site, was also seen as attractive, well maintained, and bright by a majority of the panel. Station 3, which was lit by a flat-lens luminaire from a different manufacturer, was also seen as attractive by a majority of the panel. Station 4, which was lit by the same type of luminaire as formed the original lighting at the evaluation site, was perceived as bright and glaring by a majority of the panel.

Table 9. Number of panel members who listed each word for the different gas stations visited

Word	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Attractive	2	5	4	2	3	1
Ugly	3	0	0	2	0	2
Well-maintained	3	4	3	3	3	2
Run-down	2	0	0	0	1	0
Clean	4	5	4	4	4	4
Dirty	1	0	0	0	0	1
Bright	3	4	3	5	1	3
Dark	1	0	1	0	1	0
Sparkling	0	2	0	1	0	0
Drab	0	0	2	0	3	2
Colorful	1	2	0	0	0	0
Colorless	1	0	0	0	2	2
Modern	1	1	2	2	1	1
Old-fashioned	0	0	0	0	2	0
Expensive	1	0	0	1	0	0
Cheap	1	0	0	0	2	0
Safe	2	3	3	3	1	1
Dangerous	0	0	0	0	0	0
Comfortable	2	3	2	1	1	1
Glaring	3	1	0	5	0	0

4.6 Sales data

Gas station owners supplied the daily number of gallons of gas of all grades sold at the station from May 1, 2000, to May 31, 2001. Examination of these data revealed a regular weekly pattern of sales, with minima on Sunday or Monday and maxima on Thursday or Friday. To more clearly show any trend in gas sales, the daily number of gallons sold was averaged over a week, from Wednesday to the following Tuesday, inclusive. Figure 8 shows the mean daily number of gallons sold for every week from May 3, 2000 to May 29, 2001. The weeks marked with arrows correspond to the last week before the original luminaires were changed to the new flat-lens luminaire (April 18 to April 24, inclusive); the week following the installation of the new flat-lens luminaire (April 25 to May 1, inclusive), and the first week for which the new drop-lens luminaire was installed (May 2 to May 8, inclusive). An examination of Figure 8 shows considerable variability in mean daily gallons sold. Some of this variability can be assigned to variations in gas prices, weather, and holidays. What is interesting is the evident increase in mean daily gallons sold immediately following the replacement of the original luminaires with the new flat-lens and new drop-lens luminaires. Given the variability in the data, it would be premature to conclude that the changes in the lighting produced an increase in gas sales. However, the data do suggest that a more comprehensive investigation of the relationship between gas sales and lighting conditions, covering a much longer period and a wider range of variables, would be worthwhile.

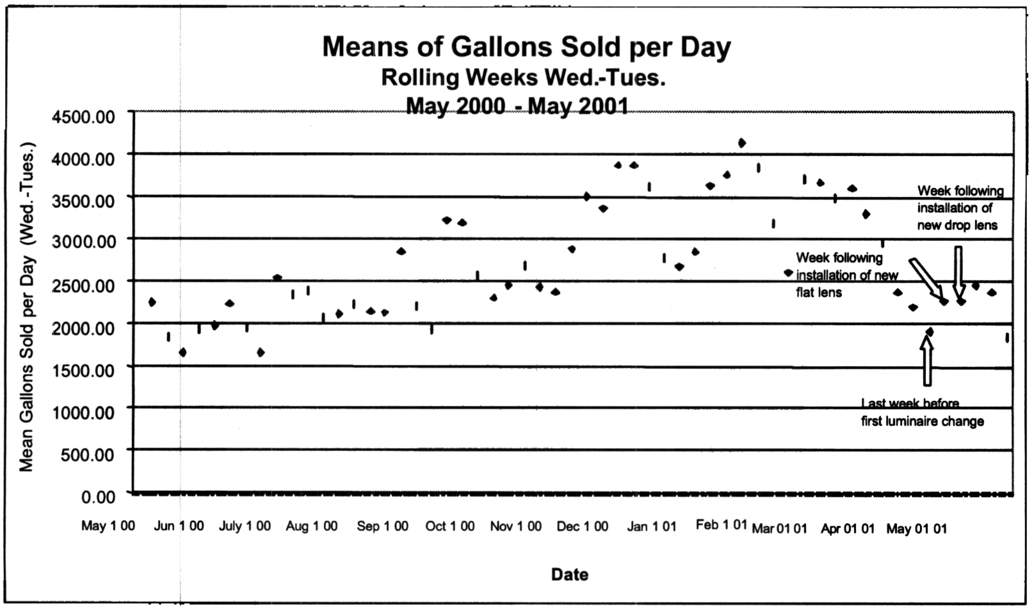

Figure 8. Weekly means of gallons sold, from Wednesday through following Tuesday

5. Discussion

From the results presented above it is possible to reach a number of conclusions, as follows:

The photometric measurements are consistent with the luminaire luminous intensity distributions. The luminaire used in the original lighting has a much wider luminous intensity distribution than the new lighting installations, resulting in the lowest illuminance under the canopy, the highest glare ratio, and the highest light trespass illuminances and illuminance ratios. These things might be regarded as disadvantages, but the drivers questioned in the gas station saw it as providing more uniform lighting over the total area of the gas station.

The percentage of drivers turning in to the gas station and the mean number of gallons of gas sold daily both show an increase for the two new lighting installations relative to the original lighting installation. This increase may be caused by the greater brightness under the canopy for the two new lighting installations and/or a dislike of the greater glare produced by the original lighting. Alternatively, it may be caused by the weather or relative gas prices. The weather was definitely warmer on the days the new lighting installations were measured than for the original lighting. If drivers put off getting gas longer when the weather is bad but then buy more gas when they have to, then the weather might also explain the increase in the percentage of drivers turning in as well as the increase in gas sales. As for gas prices, if the price at the evaluation site was different than at other nearby stations at the time of the evaluation, it could affect the number of drivers turning in. Note was taken of the prices of regular unleaded gasoline at gas stations within about one mile of the evaluation site at the time of the evaluation. For the original lighting, the evaluation site was offering regular unleaded at 154.9 c and the range of values at nearby stations was 151.9 to 155.9 c. For the new flat-lens installation, regular unleaded was offered at 159.9 c while other stations were in the range 157.9 to 162.9 c. For the new drop-lens installation, regular unleaded was offered at 167.9 c while other stations were in the range 165.9 to 171.9 c. Clearly, all these gas stations are jockeying for position in the local market, the evaluation site being in the middle of the range of prices. Whether such small variations in price are enough to explain the variation in the number of drivers turning in is a matter for conjecture. What the data do suggest is that a more comprehensive study of the relationship between lighting conditions and gas sales would be worthwhile.

The widespread use of the original lighting in gas stations is considered undesirable, probably because of its brightness and the consequent glare. The patrons questioned in the gas station saw little difference between the three lighting installations apart from the obvious differences in light distribution. However, it should be remembered that different drivers give their opinions about each lighting installation. For the panel's opinions, the same people saw six different gas stations on the same night and therefore might be expected to be more sensitive to lighting differences. For the panel, the new drop-lens cutoff lighting at the evaluation site was considered attractive, well maintained, clean, and bright, while another Sunoco station using the same non-cutoff luminaire used in the original lighting was considered clean, bright, and glaring. When asked whether they would like all gas stations to be lighted in the same way as the lighting they were looking at, the highest level of agreement was given for the evaluation site with the drop-lens cutoff luminaires and the lowest for the other Sunoco station with the drop-lens non-cutoff luminaire used in the original lighting.

6. Acknowledgements
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Appendix A: Driver Questionnaire

Gas Station Lighting Survey

Thank you for taking the time to fill out this survey. We are researchers from the Lighting Research Center at Rensselaer Polytechnic Institute in Troy, New York. We're interested in your opinions about the lighting in this gas station.

Each person who completes this survey will receive <u>one</u> free lottery ticket.

Instructions: All of the statements below are about the electric lighting in this gas station, not daylight. If you **agree** with any of the statements numbered 1 through 10, make a mark in the box labeled "Yes" to the right of the statement. If you **disagree** with the statement, mark "No."

		Agree	**Disagree**
1.	Overall, the lighting in this gas station is comfortable.	Yes ☐	No ☐
2.	The lighting is too bright for pumping gas and checking my car.	Yes ☐	No ☐
3.	The lighting is too dim for pumping gas and checking my car.	Yes ☐	No ☐
4.	There is enough light to see under the hood of my car if I need to.	Yes ☐	No ☐
5.	The lighting causes reflections that keep me from seeing well.	Yes ☐	No ☐
6.	The amount of light in different areas of this gas station varies a lot.	Yes ☐	No ☐
7.	The light fixtures are too bright when seen from the street.	Yes ☐	No ☐
8.	The lighting at this gas station attracted me to pull in.	Yes ☐	No ☐
9.	The lighting at this gas station makes me feel safe.	Yes ☐	No ☐
10.	Overall, the lighting in this gas station is attractive.	Yes ☐	No ☐

11. How does the lighting in this gas station compare to that of other gas stations you use?

worse ☐ about the same ☐ better ☐

Please mark in the box next to any words that you feel describe the lighting in this gas station.

☐ attractive	☐ old-fashioned
☐ dirty	☐ cheap
☐ well-maintained	☐ safe
☐ dark	☐ glaring
☐ sparkling	☐ expensive
☐ ugly	☐ run-down
☐ bright	☐ comfortable
☐ colorless	☐ dangerous
☐ modern	☐ clean
☐ drab	☐ colorful

Appendix B: Panel Questionnaire

Gas Station Lighting Survey - Officials

Gas Station Brand and Location: Mobil, Allen St. & Cooley St.

Instructions: All of the statements below are about the electric lighting in this gas station. Please check the box to the right of the words that match your level of agreement with the following statements:

Answer these questions while you are approaching the gas station:

1. The lighting of this gas station attracts attention.

strongly disagree ☐ slightly disagree ☐ neither agree nor disagree ☐ slightly agree ☐ strongly agree ☐

2. The lighting of this gas station would make me feel safe when using it.

strongly disagree ☐ slightly disagree ☐ neither agree nor disagree ☐ slightly agree ☐ strongly agree ☐

3. The lighting of this gas station is appropriate for the surroundings.

strongly disagree ☐ slightly disagree ☐ neither agree nor disagree ☐ slightly agree ☐ strongly agree ☐

4. The light fixtures are too bright when seen from the street.

strongly disagree ☐ slightly disagree ☐ neither agree nor disagree ☐ slightly agree ☐ strongly agree ☐

5. Please check the box next to any words that you feel describe the lighting of this gas station.

☐ attractive	☐ old-fashioned	☐ ugly
☐ dirty	☐ cheap	☐ comfortable
☐ well-maintained	☐ safe	☐ colorless
☐ dark	☐ glaring	☐ clean
☐ sparkling	☐ expensive	☐ dangerous
☐ bright	☐ run-down	☐ drab
☐ colorful	☐ modern	

Answer these questions while you are inside the gas station:

6. The lighting of this gas station is comfortable.

strongly disagree ☐ slightly disagree ☐ neither agree nor disagree ☐ slightly agree ☐ strongly agree ☐

7. There is plenty of light for pumping gas and checking your car.

strongly disagree ☐ slightly disagree ☐ neither agree nor disagree ☐ slightly agree ☐ strongly agree ☐

8. I would like to see lighting of this type for all new gas stations.

strongly disagree ☐ slightly disagree ☐ neither agree nor disagree ☐ slightly agree ☐ strongly agree ☐

Please write below any other comments you wish to make about the lighting of this gas station:

Appendix C: Brief descriptions of gas stations visited by the panel

Station 1 - Citgo, junction of Allen Street and Cooley Street, Springfield, MA.
The under-canopy lighting consists of 24 large, surface-mounted, drop-lens luminaires fitted with metal halide lamps. Sixteen of the luminaires have the lamp horizontal, while eight have the lamp vertical. The latter appear much brighter than the former. The illuminance on the apron under the center of the canopy is 287 lx.

Station 2 - Sunoco, 1390 Allen Street, Springfield, MA.
This station is the evaluation site. The lighting is provided by 12 recessed, Ruud drop-lens, cutoff luminaires. The illuminance on the apron under the center of the canopy is 1090 lx.

Station 3 - Shell, on Allen Street, next to the Bill Playground, Springfield, MA.
The under-canopy lighting consists of 29 small, recessed, flat-lens luminaires fitted with metal halide lamps. Two of the lamps had failed. The edge of the canopy is internally illuminated with fluorescent lamps. The illuminance on the apron under the center of the canopy is 370 lx.

Station 4 - Sunoco, junction of Sumner Avenue and White Street, Springfield, MA.
The under-canopy lighting of the canopy viewed consists of 20, surface-mounted, drop-lens luminaires fitted with vertically mounted metal halide lamps. The illuminance on the apron under the center of the canopy is 497 lx.

Station 5 - Shell, junction of Sumner Avenue and Commonwealth Street, Springfield, MA.
The under-canopy lighting consists of 15, small, recessed, shallow drop-lens luminaires fitted with metal halide lamps. Four of the lamps had failed. The edge of the canopy is internally illuminated with fluorescent lamps. The illuminance on the apron under the center of the canopy is 122 lx.

Station 6 - Cumberland Farms, junction of Sumner Avenue and Belmont Avenue, Springfield, MA.
The under-canopy lighting consists of eight, small, surface-mounted, shallow drop-lens luminaires fitted with horizontal metal halide lamps. The illuminance on the apron under the center of the canopy is 311 lx.